MODELING THE EFFECTS OF MULTI-STAGE HYDRAULIC FRACTURING ON HORIZONTAL WELL PERFORMANCE

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ABSTRACT: *In this work the effect of multistage fracking on well performance was investigated. WellFlo well modelling software was used to build a horizontal wellbore model with multistage hydraulic fractures. Three fracturing stages were considered. For the first case, the well was fractured in single stage. In the second case, the well was fractured in two stages. The first stage has two fractures and the second stage also has two fractures. For the third case, the well was fractured in three stages. Hence the first stage has two fractures, the second stage has two fractures, while the third stage has three fractures. The consequences of fracture skin and fracture permeability were sensitized on. Result reveals that the liquid production rate was maximum when the well was fractured in three stages for a given fracture permeability.Result also indicates a well productivity index of 0.0731 STB/d/psi and an absolute open flow potential of 347 STB/day for the unfractured reservoir, 127.3 STB/day of oil, 264.4 STB/day of oil at a flowing bottom hole pressure of 1455.06 psig for two stage fracking, 453.8 STB/day of oil at a flowing bottom hole pressure, and 1842.27 psig for single stage fracking1395.43 psig for three stage fracking. Based on the result of this study it is suggested that formation should be fractured in three stages so as to maximize fluid production.*

KEYWORDS: *fractured reservoir, Hydraulic fracturing, Permeability, Modelling,*

INTRODUCTION

Low-permeability formations such as tight oil and gas reservoirs would not produce economically unless a successful hydraulic fracturing treatment is designed. Hydraulic fracturing has undergone several noteworthy advancements in recent decades, particularly concerning its design and strategy to address the distinct features and intricacies of reservoirs that contain naturally occurring fractures. The productivity increases with complexity of fracture network systems in low permeability reservoirs. Optimizing productivity through analysis of the flow characteristics, reservoir properties, and efficient fracture treatment design that impacts well performance is essential for the successful development of low permeability reservoirs [4].

There are a number of explanations put forth for why multi-stage hydraulic fracturing is superior to alternative methods. More "superhighways" are available from multi-stage hydraulic fractures than from single-stage fractured vertical wells. Furthermore, the contacted reservoir area may be significantly expanded by the increasing stages.When the spacing is small, adding more fractures would not significantly increase production. [2]. The optimization of fracture properties is a primary concern in hydraulic fracturing. Stimulated reservoir volume (SRV) is increased by the interaction of hydraulic fractures and the natural-fracture network [10]; [15]. The success of horizontal well development on a constant surface pressure depends on figuring out the ideal number of treatments, spacing, and completion efficiency. [7]. Predicting stimulated fractures based on well performances is essential to optimize treatment designs and determine the appropriate number of hydraulic fracturing stages. Wellflo software was utilized in this study to forecast how various stages of hydraulic fracturing would affect well performance.

MATERIALS AND METHOD

2.1 Materials

The materials used for this study are wellflo modeling package, fluid property data, reservoir data, deviation survey data, geothermal gradient, fracture properties

2.1.1 Input data:

Fluid properties data (gas gravity, water salinity, mole fraction of gaseous impurities, water/gas ratio), reservoir data (pressure, temperature, mid perforation depth, permeability, thickness, wellbore radius, water/gas ratio), deviation survey data (measured depth versus true vertical depth), downhole equipment (casing and tubing setting depth, branch, tie point, internal diameter and wall roughness), geothermal gradient (formation temperature against measured depth) and the overall heat transfer coefficient etc. Relative permeability data (Gas/water end point permeability and Oil/water end point permeability data) fracture properties (length, width, height, number of fractures, fracture dimensions, and fracture permeability)

2.1.2 Method

WellFlo version 6.1.0 was used in this study. To investigate the impact of multistage hydraulic fracturing on well performance, it was necessary to build a wellbore model in Wellflo software. The well has a horizontal lateral section of 3000ft. The fluid model used was the black oil model. The well has a gas oil ratio of 500 SCF/STB, oil gravity of 35°API, gas gravity of 0.65, water cut of 0.15 and water salinity of 30,000 PPM. The flow correlation chosen to calculate P_b, R_s and B_o was Glaso and that for μ_o, μ_g and σ were Beal *et al*, Carr *et al*, and Basic respectively. The reservoir has a pressure of 6000psia, temperature of 196°F and a permeability of 1.2mD. The flow type is tubing and the well orientation was Multifrac with Vogel model chosen as the IPR model. The flow correlation chosen for the vertical lift performance was the Hagedorn and Brown correlation. In the reference depth tab, the onshore well type option as selected and the zero depth was set to Rotary Kelly Bushing (RKB). Wellbore deviation survey, Thewellbore consists of a vertical section up to a measure depth of 5000ft and after that, it has a horizontal section down to 12000ft.
The fracture properties are as given in Table 1.

Table 1: Fracture properties for case 1

	1st Stage	
Fracture	1	2
Fracture Spacing (ft)	400	300
Fracture width (ft)	0.02	0.02
Fracture Half Length (ft)	450	450
Fracture Height (ft)	200	200
Near -Wellbore Fracture Permeability (mD)	55000	55000
Near -Wellbore Fracture width (ft)	0.01	0.01
Fracture Permeability (mD)	60000	60000
Measured skin	1	1

Case 2

In the second case, the well was fracture in two stages. The first stage has two fractures while the second stage also has two fractures. The fractures properties for case 2 is shown in Table.2.

Table 2: Fracture properties for case 2

	1st Stage		**2nd Stage**	
Fracture	**1**	**2**	**1**	**2**
Fracture Spacing (ft)	400	300	300	400
Fracture width (ft)	0.02	0.02	0.02	0.02
Fracture Half Length (ft)	450	450	450	450
Fracture Height (ft)	200	200	200	200
Near -Wellbore Fracture Permeability (mD)	55000	55000	55000	55000
Near -Wellbore Fracture width (ft)	0.01	0.01	0.01	0.01
Fracture Permeability (mD)	60000	60000	60000	60000
Measured skin	1	1	1	1

Case 3

In the third case, the well was fracture in three stages. The first stage has two fractures, the second stage has two fractures, while the third stage has one fractures. The fractures properties for case 3 is shown in Table 3.
Table 3. Fracture properties for case 3

	1st Stage		2nd Stage		3rd Stage
Fracture	**1**	**2**	**1**	**2**	**1**
Fracture Spacing (ft)	400	300	400	300	400
Fracture width (ft)	0.02	0.02	0.02	0.02	0.02
Fracture Half Length (ft)	450	450	450	450	450
Fracture Height (ft)	200	200	200	200	200
Near -Wellbore Fracture Permeability (mD)	55000	55000	55000	55000	55000
Near -Wellbore Fracture width (ft)	0.01	0.01	0.01	0.01	0.01
Fracture Permeability (mD)	60000	60000	60000	60000	60000
Measured skin	1	1	1	1	1

The following are the assumptions made while developing the wellbore model:

i. Multi-stage hydraulic fracturing opens up the natural fractures in tight reservoir, which can be described by a dual permeability model. However, these natural fractures get activated only in the stimulated region while in the unstimulated region, tight matrix is the primary means of flow.

ii. Hydraulic fractures are vertical and symmetric around the horizontal well.

Table 2: Wellbore deviation survey

MD (ft)	TVD (ft)
5000	5000
6000	5980
6500	6450
7000	6870
7500	7200
8000	7400
8500	7500
9000	7550
9500	7552
10000	7556
10500	7556
11000	7558
11500	7560
12000	7562

In the equipment data tab, two casing strings were defined. The first casing starts at 20ft and ends at 7500ft. It has an external diameter of 7-inch and internal diameter of 6.184-inch while the second casing string starts at 7500ft and ends at 12000ft with an external diameter of 7-inch and internal diameter of 6.184-inch. Also, a tubing with an external diameter of 3.5-inch and internal diameter of 2.992-inch which started at 20ft and ended 7500ft was installed. In the temperature model tab, the temperature survey is shown Table 3

Table 3: Temperature Survey

MD	Temperature (°F)
20	80
1000	95
2000	105
3000	115
4000	125
12000	188

The completion interval was set at 12000ft. The completion interval is 100ft TVD and the wellbore has a radius of 0.42ft. In the drainage area geometry tab, an equivalent radius of 912.10ft was defined. The gas/water, gas/oil and oil/water endpoint permeability defined in the relative permeability section is as shown in Tables 6, 7 and 8 respectively.

Table 4: Gas/Water Endpoint permeability

Parameter	Value
Krg	1
Krw	0.5
Swi	0.25
Srg	0.3
M	3.5
N	2

Table5.: Gas/Oil Endpoint permeability

Parameter	Value
Kro	0.75
Krg	0.85
Sgc	0.15
Srog	0.15
M	1.7
N	2.4

Table.6: Oil/Water Endpoint permeability

Parameter	Value
Kro	1
Krw	0.5
Swi	0.25
Sor	0.3
M	3.5
N	2

RESULTS AND DISCUSSION

3.1 Well Inflow Performance Relationship (IPR) for single stage hydraulic fracturing

The well Inflow performance relationship (IPR) curve for the case 1 is shown in Fig.1. This single stage hydraulic fracture has two fractures with fracture properties as shown in Table 1. Result reveals that the well will have a productivity index of 0.0374 STB/d/psi and a 177.3 STB/day absolute open flow potential.

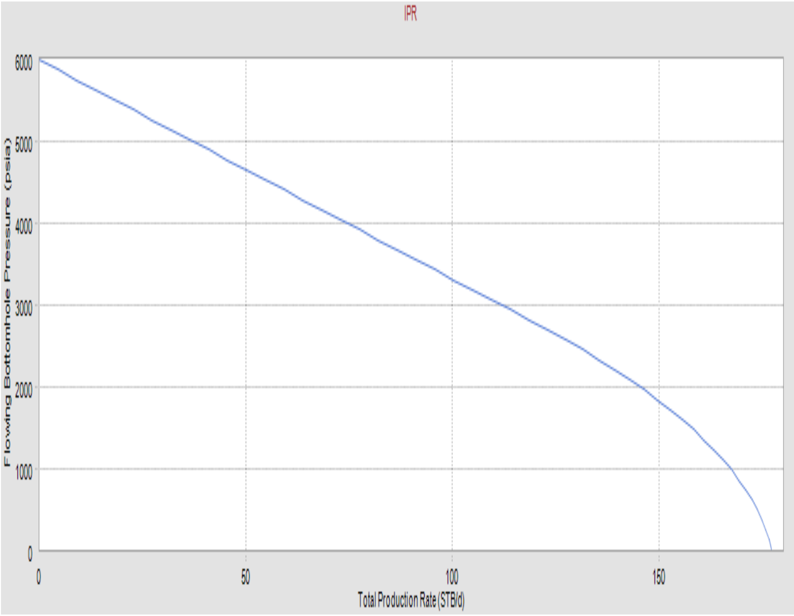

Fig.1: Inflow performance relationship for the case of one stage hydraulic fracturing

The input and outflow performance curves for the single stage hydraulic fracturing case are displayed in Fig. 2. The system's operating point is represented by the point where the inflow and outflow performance curves intersect. The well will yield 127.3 STB/day of oil, according to the results. This is the point where the inflow and outflow performance curves intersect, and the flowing bottom hole pressure at this location is 1842.27 psig.

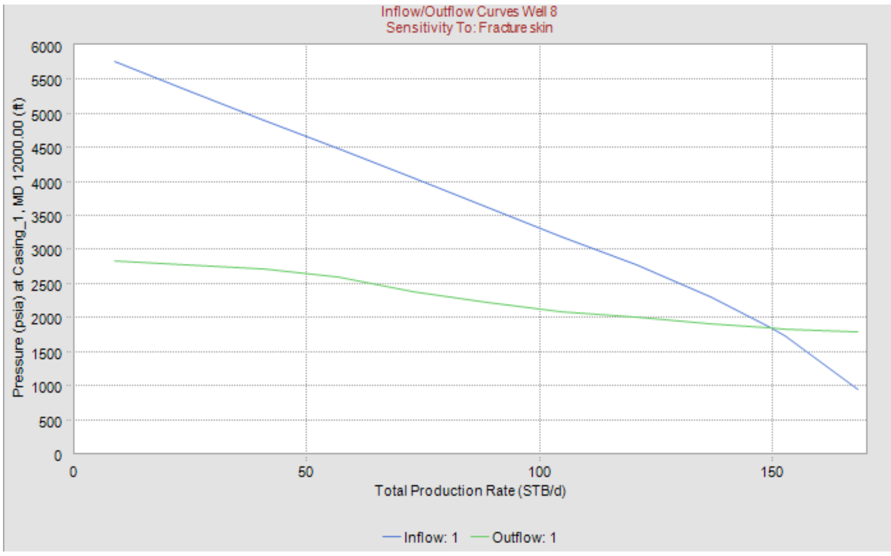

Fig 2: Inflow/Outflow curve for single stage hydraulic fracturing

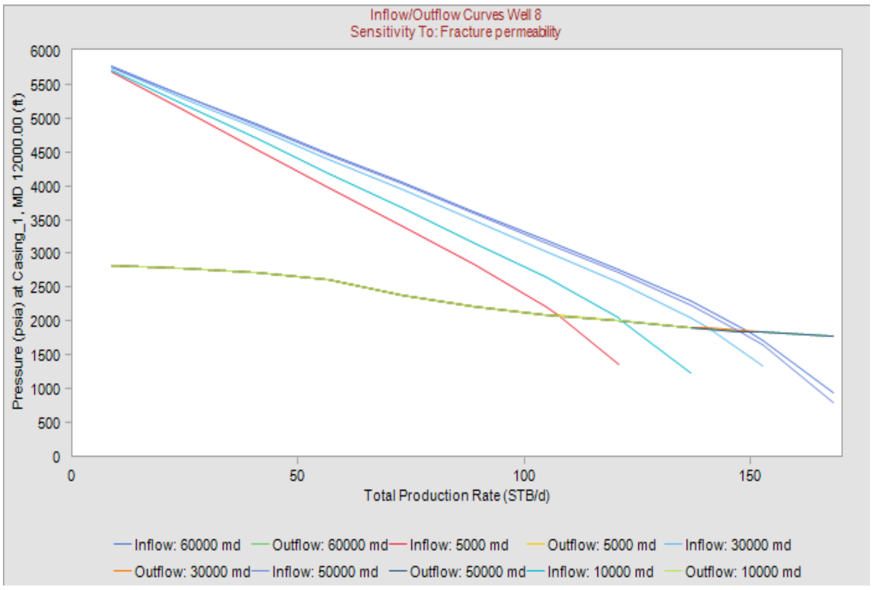

Fig.3: Sensitivity result for the effect of fracture permeability on well performance

3.2 Effect of two stage hydraulic fracturing on well performance

In this case, the formation was fractured in two stages. This stage has two fractures with fracture properties as shown in Table 1. The IPR curve for the case in which the reservoir was fractured in two stages is shown in Fig 4.. Result gave a productivity index of 0.0731 STB/d/psi and an absolute open flow of 347 STB/day.

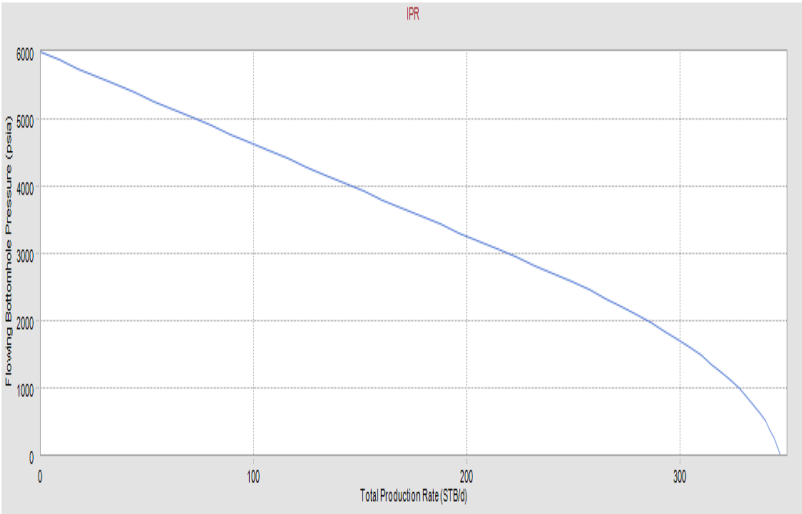

Fig. 4: IPR plot for two stage hydraulic fracturing.

The two-stage hydraulic fracturing case's inflow and outflow performance curves are displayed in Fig. 5. The intersection point of the inflow and outflow performance curves, which is 264.4 STB/day, and the flowing bottom hole pressure at this location, which was 1455.06 psig, are the results.

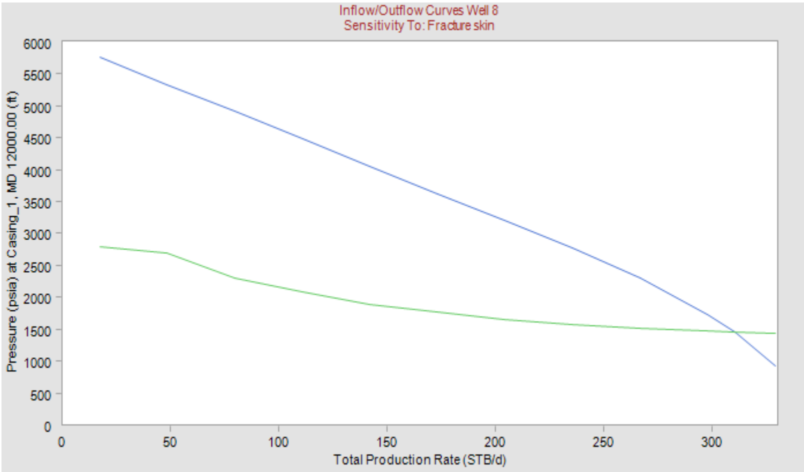

Fig. 5: Inflow/Outflow curve for two stage hydraulic fracturing.

3.3 Effect of fracture permeability for two stage hydraulic fracturing

For the sensitivity runs, fracture permeabilities of 5000, 10000, 30000, 50000, and 60000mD were taken into consideration in order to ascertain the impact of fracture permeability on well performance for two stages of fracturing. The well performance curves for the impact of fracture permeability on well performance are displayed in Figure 6. The intersection of the inflow and outflow performance curves shifts downward as fracture permeability increases, as shown by the results, suggesting an increase in the rate of oil production.

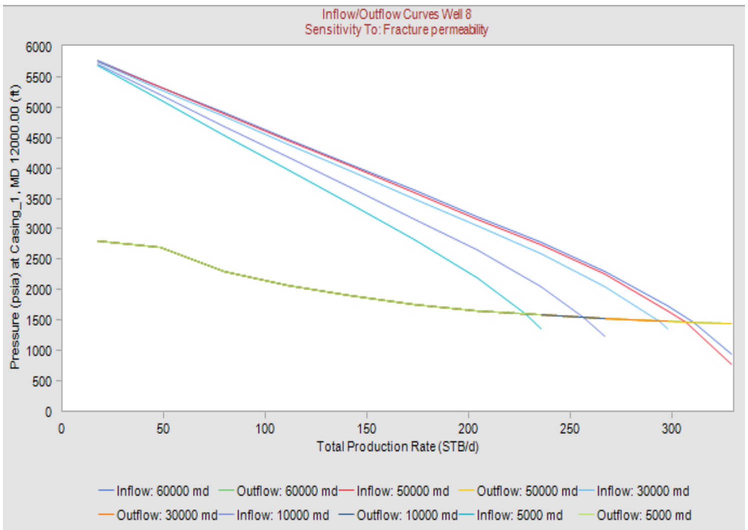

Fig. 6 Effect of fracture permeability in two stage hydraulic fracturing.

3.4 Effect of three stage hydraulic fracturing on well performance

The IPR curve for the case in which the reservoir was fractured in three stages is as shown in fig.7. Result indicates that the well have a productivity index of 0.1245 STB/d/psi and an absolute open flow potential of 590.8 STB/d.

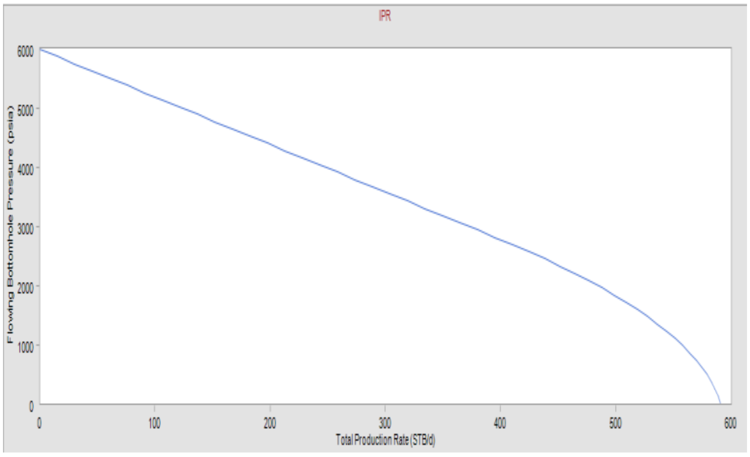

Figure 7: Inflow performance curves for three stage hydraulic fracturing

The three-stage hydraulic fracturing case's inflow and outflow performance curves are displayed in Figure 8. The system's operating point is represented by the point where the inflow and outflow performance curves intersect. The well will yield 453.8 STB/day of oil, according to the results. This is the point where the inflow and outflow performance curves intersect, and the flowing bottom hole pressure at this location is 1395.43 psig.

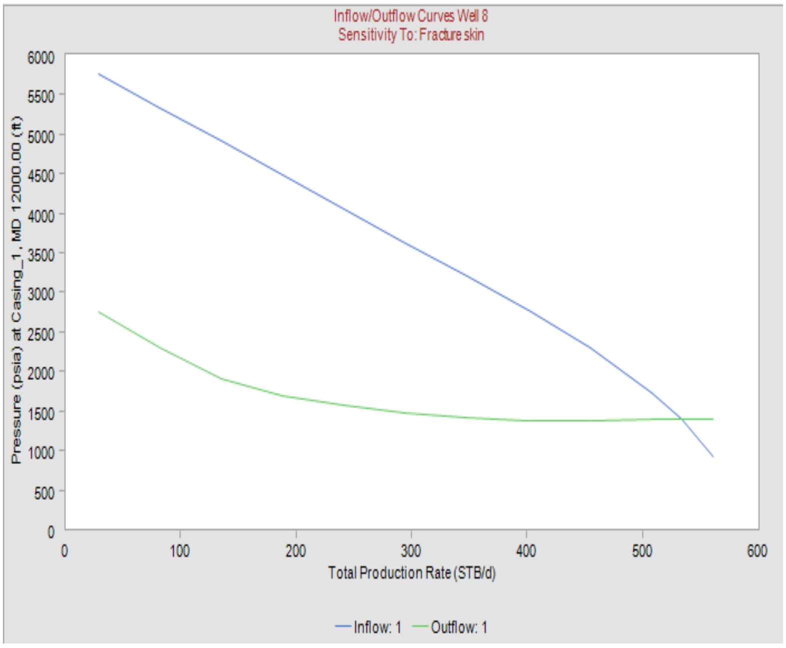

Fig.8 Inflow/Outflow performance curves for the effect of three stage hydraulic fracturing

3.5 Effect of fracture permeability in three stage hydraulic fracturing

For the sensitivity runs, fracture permeabilities of 5000, 10000, 30000, 50000, and 60000mD were taken into consideration in order to ascertain the impact of fracture permeability on well performance in the scenario where the well was fractured in two stages. The findings show that the intersection of the inflow and outflow performance curves moves downward with increasing fracture permeability, indicating a rise in the rate of oil production.

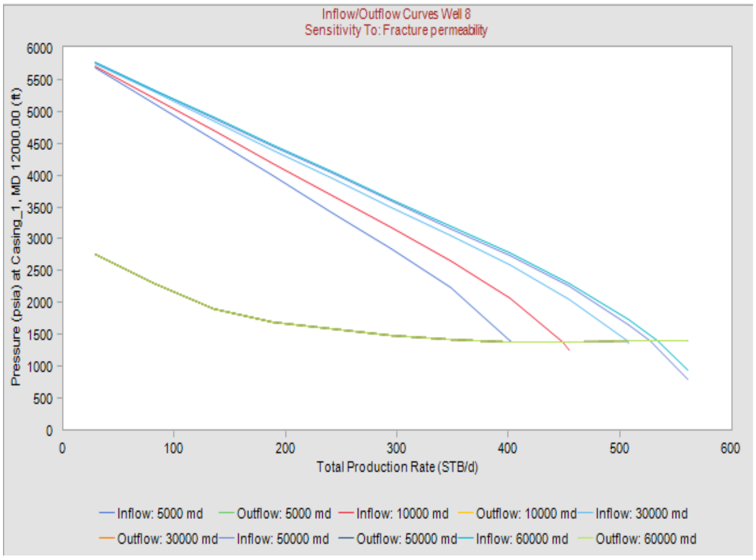

Fig.9: Well performance for the effect of fracture permeability in three stage hydraulic fracturing.

3.6 Comparison of the stages of hydraulic fracturing

Fig.10 shows the absolute open flow potential from the well when the well was fractured in single, two and three stages. Results reveal that as the number of hydraulic fracturing stages increases, the maximum production rate that can be obtained from the well also increases. The figure shows that the absolute open flow potential for the single, two and three stages were 177.3, 347 and 590.8STB/d-psi., respectively.

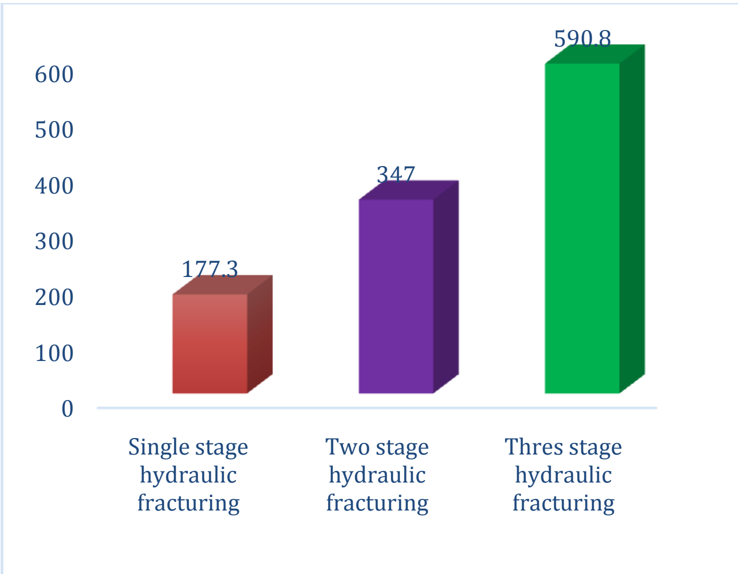

Fig.10: Comparison of the absolute open flow potential for the three stages of hydraulic fracturing.

CONCLUSIONS

The impact of multistage hydraulic fracturing on well performance was examined in this study.WellFlo well modelling software package was used to build a horizontal wellbore model with multistage hydraulic fractures. Three fracturing stages were considered. For the first case, the well was fracture in one stage. In the second case, the well was fracture in two stages. There are two fractures in the first stage and two more in the second stage. For the third case, the well was fracture in three stages. The first stage has two fractures, the second stage has two fractures, three fractures are present in the third stage. Sensitization was applied to the effects of fracture permeability and skin.

From this study, the following conclusions are made:

For a given fracture permeability, the well's maximum rate of liquid production occurred when the well fractured in three stages.

Result indicates a well productivity index of 0.0731 STB/d/psi and an absolute open flow potential of 347 STB/day for the unfractured reservoir.
Result reveals that the well will produce 127.3 STB/day of oil, at a flowing bottom hole pressure of 1842.27 psig for the single stage, 264.4 STB/day of oil at a flowing bottom hole pressure 1455.06 psig for two stage hydraulic fracturing, 264.4 STB/day of oil at a flowing bottom hole pressure of 1455.06 psig, 453.8 STB/day of oil at a flowing bottom hole pressure 1395.43 psig for three stage hydraulic fracturing.

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